PATENT SPECIFICATION

(11) 1 580 335

(21) Application No. 26773/77 (22) Filed 27 June 1977
(23) Complete Specification filed 24 May 1978
(44) Complete Specification published 3 Dec. 1980
(51) INT CL³ G01R 27/26
(52) Index at acceptance
G1U JB4A
(72) Inventor BRIAN EDWARD WHITMORE

1 580 335

(19)

(54) CAPACITANCE-TO-FREQUENCY CONVERTER

(71) We, W. & T. AVERY LIMITED, of Smethwick, Warley, West Midlands B66 2LP, a British Company, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed to be particularly described in and by the following statement:—

This invention relates to a capacitance-to-frequency (CF) converter for producing a pulsed output whose frequency is proportional to the value of a capacitor. The invention is particularly, but not necessarily exclusively, applicable to a capacitive-type transducer where the value of a capacitor changes with variations in a physical quantity, e.g. weight, to which the transducer is responsive. Thus, where the transducer capacitance is proportional to displacement of a force-receiver the frequency output of the CF converter may be proportional to displacement.

According to a broad aspect of the present invention we provide a capacitance-to-frequency (CF) converter comprising a capacitor connected to the input of a capacitance-to-voltage (CV) converter, an integrator connected to the output of the CV converter and switching means connected to the integrator output, the output of the switching means being applied to said capacitor to form a circuit loop which is arranged to operate in an oscillatory mode so as to produce, at the output of the switching means, a pulse train whose frequency is proportional to said capacitor.

According to a more specific aspect of the present invention we provide a CF converter comprising a variable capacitor connected to the input of a CV converter, an integrator connected to the output of the CV converter and switching means connected to the output of the integrator, the switching means being switchable alternately between first and second voltage levels each time the integrator output attains respective predetermined threshold values such that the switching means produces a substantially rectangular waveform output whose limits are defined by said voltage levels, the switching means output being applied to said capacitor to form a circuit loop which is arranged to operate in an oscillatory mode whereby the frequency of said rectangular waveform is proportional to the capacitance of said variable capacitor.

Thus, the voltage applied to the capacitor by the switching means is converted by the CV converter into an output which is proportional to the product of the capacitor and the output voltage from the switching means. The output from the CV converter forms the input signal of the integrator whose output will change linearly with time at a rate that is proportional to the input voltage level. The output voltage from the integrator will ramp from one threshold level of the switching means to the other. When the integrator output reaches a threshold level of the switching means, the output of the switching means changes its level producing a change in the output from the CV converter which causes the integrator output to ramp back towards the threshold level it had come from. Since the time taken for the integrator output to ramp from one threshold level to the other is inversely proportional to the rate of change of voltage at the integrator output then the output frequency will be proportional to the input capacitor times the switching means output voltage. If the output voltage levels of the switching means applied the variable capacitor are maintained constant or if the difference between the input threshold voltages of the switching means is made proportional to the difference between the output levels of the switching means then the output frequency is proportional to the input capacitor of the CV converter.

The present invention also includes within its ambit, a modification of the CF converter as defined hereinabove in which said capacitor forms one of a pair of capacitors connected to the input of the CV converter, the arrangement being such that the output from the switching means is applied to both capacitors in such a way that the voltage applied to one capacitor is in anti-phase with that applied to the other.

The advantage of this two capacitor-input CV converter is that the output frequency corresponding to the initial values of the two capacitors can be made lower than the frequency corresponding to the single capacitor and yet the change in frequency for a given change in the value of the first capacitor of the pair can be made substantially the same as for a given change in the single capacitor case. Thus, with this arrangement, small percentage changes in capacitance can be made to produce large output frequency changes.

Other features that stem from the CF converters of the invention are the capability of producing an output frequency which is largely independent of stray capacitance effects, environmental effects (e.g. temperature changes) and circuit supply voltage, as will be explained hereinafter with reference to preferred embodiments of the invention.

The invention will now be described by way of example with reference to the accompanying drawings, in which:

Figure 1 is a circuit diagram of the CF converter;

Figure 2 is a diagram of the same circuit as in Figure 1 but showing the stray capacitances that may be present and also including a modification that may, in some instances, be necessary in order that the circuit will automatically oscillate;

Figure 3 is a circuit diagram of a CF converter with a two-capacitor input; and

Figure 4 shows the waveforms which appear at points 1, 2 and 3 in the circuit of Figure 1.

As will be seen from Figure 1, the CF converter comprises a CV converter stage, an integrator stage and a switching stage, each stage comprising an operational amplifier or amplifiers A1—A4 connected in appropriate configuration with circuit components C2—C4 (capacitors) and R1—R5 (resistors). The amplifiers A1—A4 all have their non-inverting inputs connected to the common rail (earthed) and thus operate in the inverting mode. The capacitor C1, which may constitute the variable capacitance of a load-responsive transducer, is coupled to the input of the CV converter whose output is coupled to the integrator whose output, in turn, is coupled to the switching stage. The output of operational amplifier A3 is applied to the input capacitor C1. In essence the switching means shown operates as would a Schmitt trigger device having input hysteresis, which feeds into a signal inverter; both the Schmitt trigger and inverter being commercially available. The waveforms arising at points 1, 2 and 3 in the circuit are illustrated in Figure 4.

Operation

For the correct operation of the circuit arrangement the operating frequency should be high enough to make the impedance of C3 very much less than the impedance of resistors R1 and R2 in parallel. When this condition prevails the output to input voltage relationship of the capacitance to voltage means is given by $-C1/C2$.

Consider the output voltage of operational amplifier A3 to switch from V3 to −V3 when the output voltage of the operational amplifier A4 switches from −V4 to V4.

The threshold voltage range at the input to the switching means is given by $VT=2\ R4 . V4/R5$.

The output of the capacitance to voltage means will be $V1=-C1 . V3/C2$ when the output from operational amplifier A3 is V3 and will be $V1=C1 . V3/C2$ when the output voltage of operational amplifier A3 is −V3.

The output voltage from the integrator is given by $V2=-V1 . t/C4 . R3$ where t is time.

Thus $V2=\pm C1 . V3 . t/C2 . C4 . R3$ according to the polarity at the output of operational amplifier A3.

Let $t=T1$ when V2 changes by VT, then $2\ R4 . V4/R5=T1\times(C1/C2)\times V3/C4 . R3$.

The period of the waveform is given by

$$T=2\ T1=(4\ R4/R5)\times(C2/C1)\times C4 . R3 . V4/V3$$

and the frequency by

$$f=(R5/4\ R4)\times(C1/C2)\times V3/C4 . R3 . V4 \qquad (1)$$

If (R5/4 R4)×(1/C2)×V3/C4 . R3 . V4 is constant, i.e. equal to k, then the output frequency f is proportional to capacitor C1, i.e. f=kC1 and Δf/ΔC1=k.

If V3 and V4 vary with supply voltage but their ratio V3/V4 remains constant then the output frequency is independent of the supply voltage.

By constructing capacitor C2 in a similar way to capacitor C1 and subjecting them to the same environmental effects, the effects of temperature and humidity on the output frequency can be minimised.

As will now be explained, this circuit is largely independent of stray capacitance effects. Figure 2 illustrates the important stray capacitance sources present in the circuit of Figure 1 when capacitor C1 is the variable and both C1 and C2 are of like construction. Thus, the stray capacitance associated with capacitor C1 is represented by capacitor components CS1, CS2 and CS3 and the stray capacitance associated with capacitor C2 is represented by capacitor components CS4, CS5 and CS6. The effects of the capacitor components CS3 and CS4 shunting the operational amplifier A1 input can be neglected if the gain of the operational amplifier is high enough to make the current taken by these capacitor components small compared to the current taken by capacitor C2. The effects of stray capacitor components CS1 and CS6 can be neglected if the current taken by these is very much smaller than the output current capability of the operational amplifiers. The effects of capacitor components CS2 and CS5 can be taken into account if in the equation (1) for frequency f the capacitor C1 is replaced by C1+CS2 and capacitor C2 is replaced by C2+CS5.

This gives

$$f=(R5(C1+CS2)/4\ R4(C2+CS5))\times(1/C4R3)\times V3/V4$$
$$=(k\ .\ C1/(1+CS5/C2))+k\ .\ CS2/(1+CS5/C2)$$

where

$$k=(R5/4\ R4)\times(1/C2)\times V3/C4\ .\ R3\ .\ V4$$

This can be expressed as

$$f=k1\ .\ C1+f0$$

where

$$K1=k/(1+CS5/C2)$$

and

$$f0=k\ .\ CS2/(1+CS5/C2)$$

Thus the minimum operating frequency is f0, which is usually low enough not to be a problem. The value k1 can be adjusted by circuit component changes to give the required relationship between change in frequency and change in capacitor C1. Thus, the output frequency is largely independent of stray capacitance effects; Δf/ΔC1=k1 when C1 is the variable.

With some combinations of circuit component values the capacitance to frquency means may not start oscillating when the supply voltage is switched on, so a resistor shown as R6 in Figure 2 is included in the circuit to ensure self-starting. The capacitance to frequency relationship is modified by resistor R6 in a similar way to that produced by stray capacitance component CS2, namely a fixing of the minimum operating frequency to a frequency above zero.

Figure 3 shows a modification in which the circuit of Figure 1 includes a second input capacitor C5 to which the output of amplifier A4 is applied. The voltage applied to capacitor C5 is therefore in anti-phase to that applied to capacitor C1. The voltage at the output of operational amplifier A1 is then given by

$$V1=-(C1\ .\ V3-C5\ .\ V4)/C2$$

The output frequency is given by

$$f=(R5/4\ R4)\times((C1\ .\ V3-C5V4)/C2)\times(1/V4\ .\ C4\ .\ R3)$$

and if V3/V4=a constant K then

$$f=(R5/4\ R4)\times(C1K-C5)/C2)\times 1/C4R3$$
$$=k(C1K-C5)$$

With the two input capacitor arrangement the frequency corresponding to the initial values of capacitors C1 and C5 can be made lower than the frequency of the single capacitor arrangement resulting from the same value of capacitor C1 and yet the change in frequency with change in capacitor C1 is approximately the same if K tends to one.

In this case, each stray capacitance affect associated with C1, C2 and C5 can be represented by three capacitor components in a similar manner to that for the single input capacitor arrangement. Again the effects of the capacitor components shunting the operational amplifier inputs and those between the operational amplifier outputs and the common rail can be neglected provided the conditions stipulated for single capacitor input arrangement prevail.

If the stray capacitance components shunting capacitors C1, C2, and C5 are CS2, CS5 and CS8 respectively, then the output frequency equation becomes

$$f=(R5/4\ R4)\times([(C1+CS2)K-(C5+CS8)]/(C2+CS5))\times 1/C4R3$$
$$=k[(C1+CS2)K-(C5+CS8)]/(1+CS5/C2)$$

where K=V3/V4.

By adjusting capacitors C1 or C5 or factor K to give the required frequency the effects of CS2 and CS8 are taken into account and even like variations in these capacitance components CS2 and CS8 are part cancelling.

The effect of component CS5 can be considered as modifying the value of k and the required frequency change for changes in capacitors C1 and/or C5 can be achieved by adjusting one of the circuit elements included in k to allow for the effects of the stray capacitance component CS5.

Also, by constructing capacitors C1, C2 and C5 in a similar manner and subjecting them to the same environmental effects, temperature and humidity effects on the output frequency are reduced.

WHAT WE CLAIM IS:—

1. A capacitance-to-frequency (CF) converter comprising a capacitor connected to the input of a capacitance-to-voltage (CV) converter, an integrator connected to the output of the CV converter and switching means connected to the integrator output, the output of the switching means being applied to said capacitor to form a circuit loop which is arranged to operate in an oscillatory mode so as to produce, at the output of the switching means, a pulse train whose frequency is proportional to said capacitor.

2. A CF converter comprising a variable capacitor connected to the input of a CV converter, an integrator connected to the output of the CV converter and switching means connected to the output of the integrator, the switching means being switchable alternatively between first and second voltage levels each time the integrator output attains respective predetermined threshold values such that the switching means produces a substantially rectangular waveform output whose limits are defined by said voltage levels, the switching means output being applied to said capacitor to form a circuit loop which is arranged to operate in an oscillatory mode whereby the frequency of said rectangular waveform is proportional to the capacitance of said variable capacitor.

3. A modification of the converter claimed in Claim 1 or 2 in which said capacitor forms one of a pair of capacitors connected to the input of the CV converter, the arrangement being such that the output from the switching means is applied to both capacitors in such a way that the voltage applied to one capacitor is in anti-phase with that applied to the other.

4. A CF converter substantially as hereinbefore described with reference to, and as shown in, Figure 1, 2 or 3 of the accompanying drawings.

SHAW, BOWKER & FOLKES,
St. Martin's House,
Bull Ring,
Birmingham B5 5EY.
Agents for the Applicants.

Printed for Her Majesty's Stationery Office, by the Courier Press, Leamington Spa, 1980
Published by The Patent Office, 25 Southampton Buildings, London, WC2A 1AY, from which copies may be obtained.

1580335 COMPLETE SPECIFICATION

2 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 1

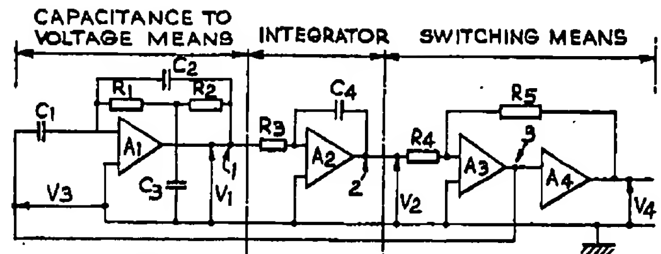

Fig. 1.

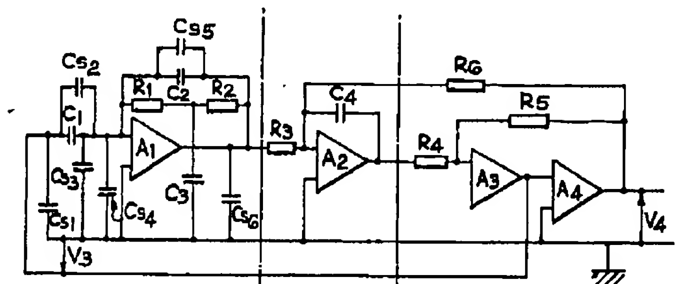

Fig. 2.

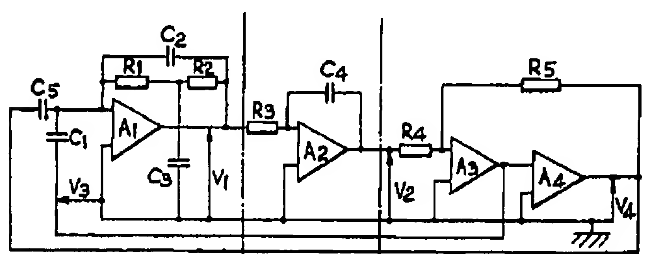

Fig. 3.

1580335 COMPLETE SPECIFICATION
2 SHEETS This drawing is a reproduction of the Original on a reduced scale
Sheet 2

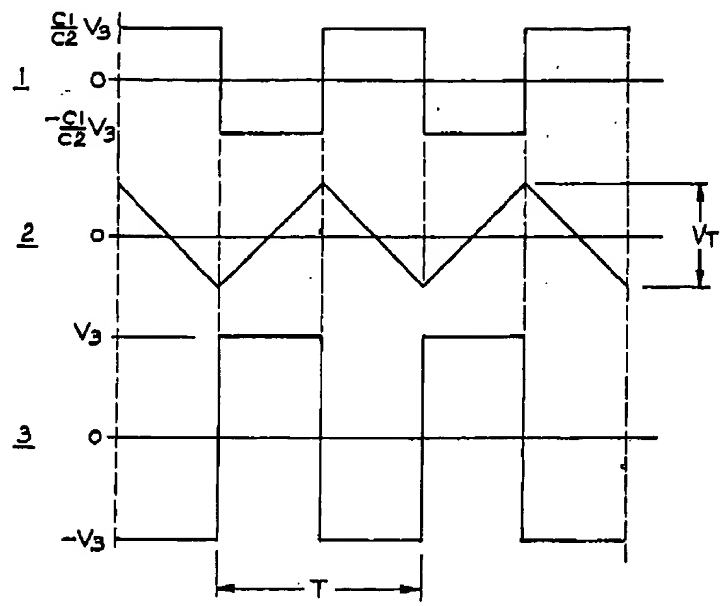

Fig. 4